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(54) METHOD AND SYSTEM FOR PRIORITIZING VEHICLE VACUUM

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F04B 49/03 (2006.01)
F02B 47/00 (2006.01)
F02D 9/02 (2006.01)

(52) **U.S. Cl.**

CPC ***F04B 49/03*** (2013.01); ***F02B 47/00*** (2013.01); *F02D 2009/024* (2013.01); *F02D 2009/0266* (2013.01)

(58) **Field of Classification Search**

CPC .. F04B 49/03; F02B 47/00; F02D 2009/024; F02D 2009/0266

See application file for complete search history.

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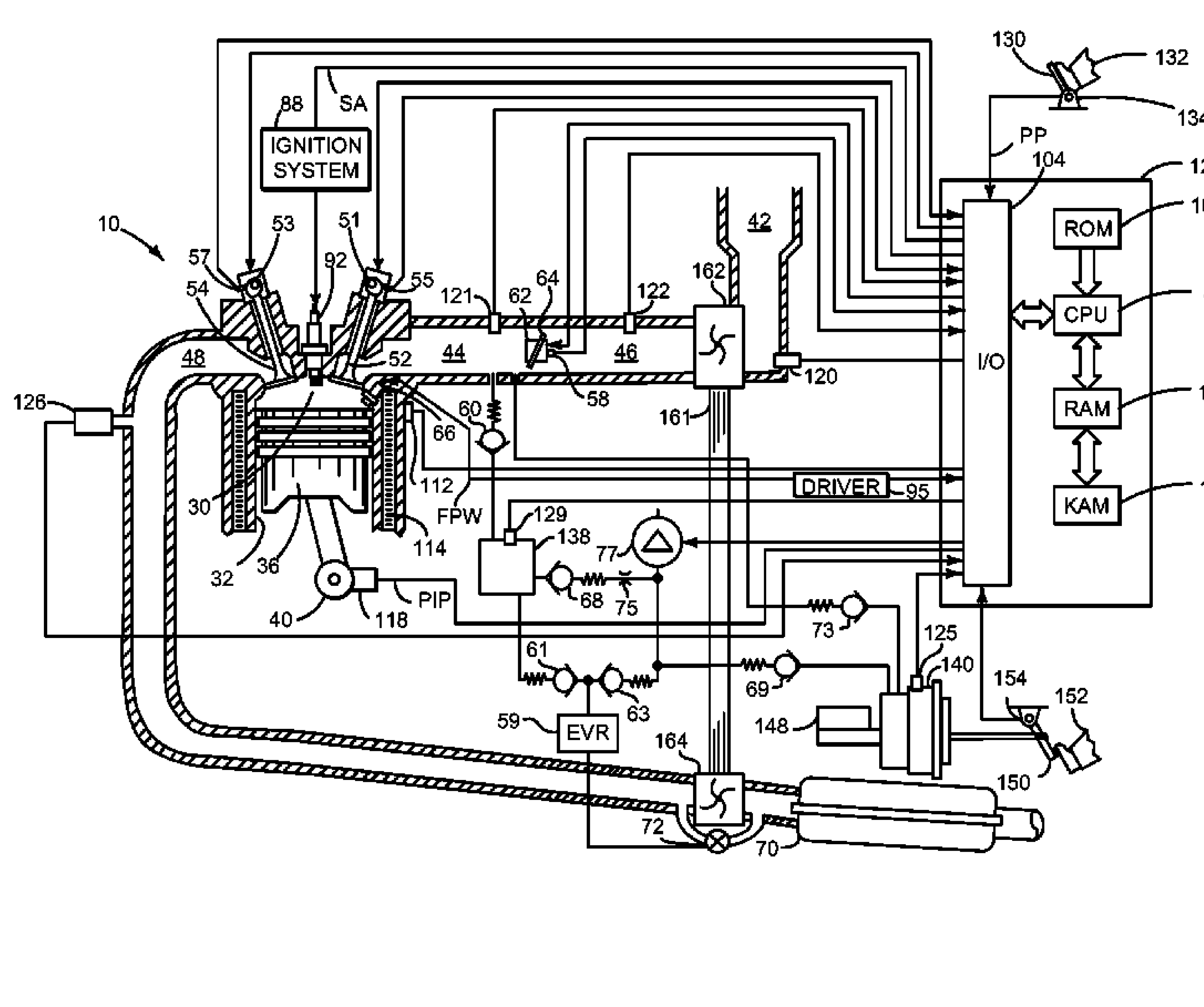
(57) **ABSTRACT**

A vacuum prioritization system for a vehicle is disclosed. In one example, use and availability of vacuum provided via vacuum sources is allocated to higher priority vacuum operated actuators when a pressure in the vacuum system exceeds a threshold pressure. The lower priority vacuum operated actuators have access to vacuum supplied via the vacuum sources when pressure in the vacuum system is less than a threshold pressure. The approach may allow higher priority actuators to operate for an extended amount of time.

19 Claims, 7 Drawing Sheets



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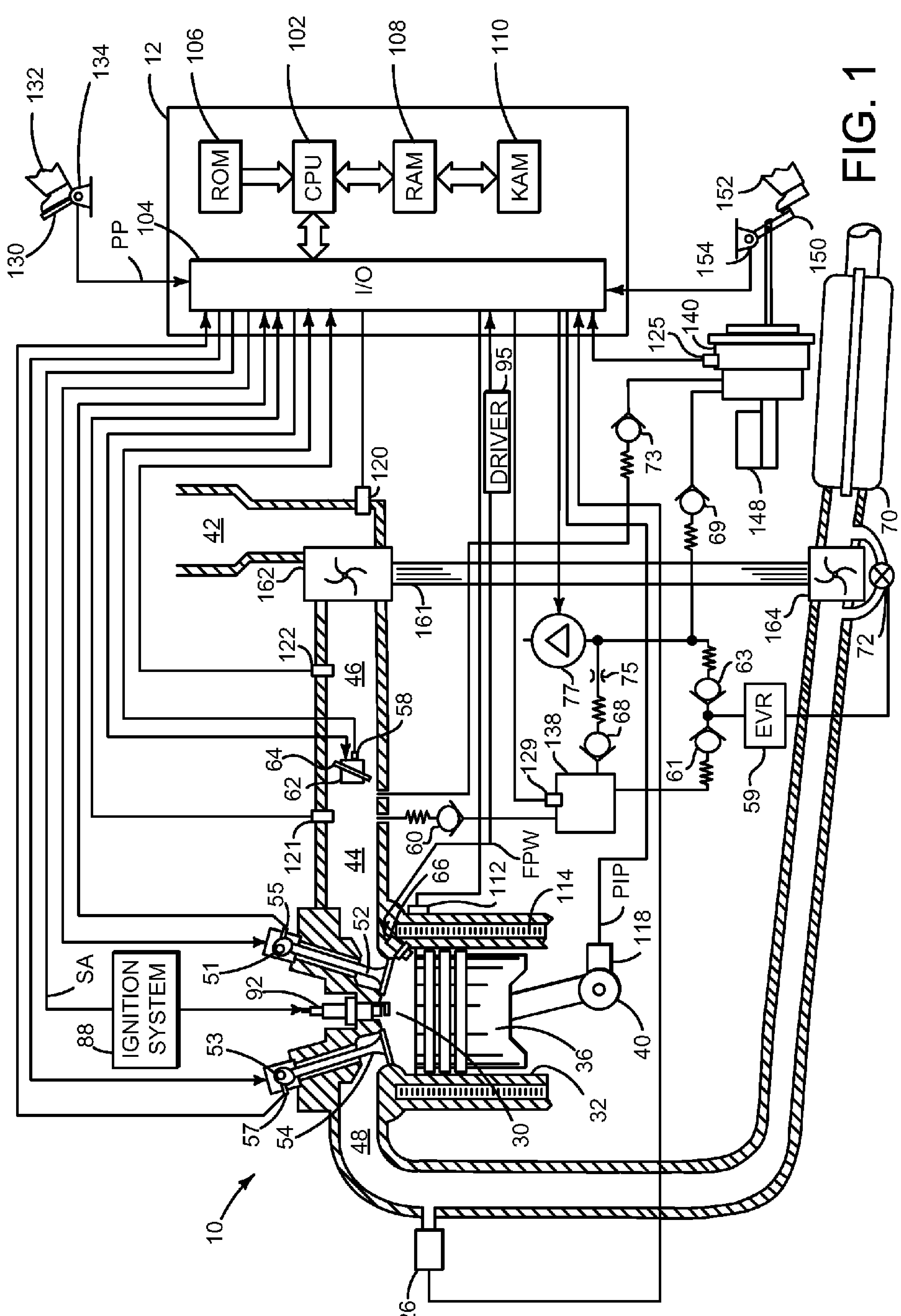
ROM
CPU
RAM
KAM
I/O
DRIVER
IGNITION SYSTEM
EVR
PP
SA
FPW
PIP
10
12
30
32
36
40
42
44
46
48
51
52
53
54
55
57
58
59
60
61
62
63
64
66
68
69
70
72
73
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92
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106
108
110
112
114
118
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152
154
161
162
164

FIG. 1

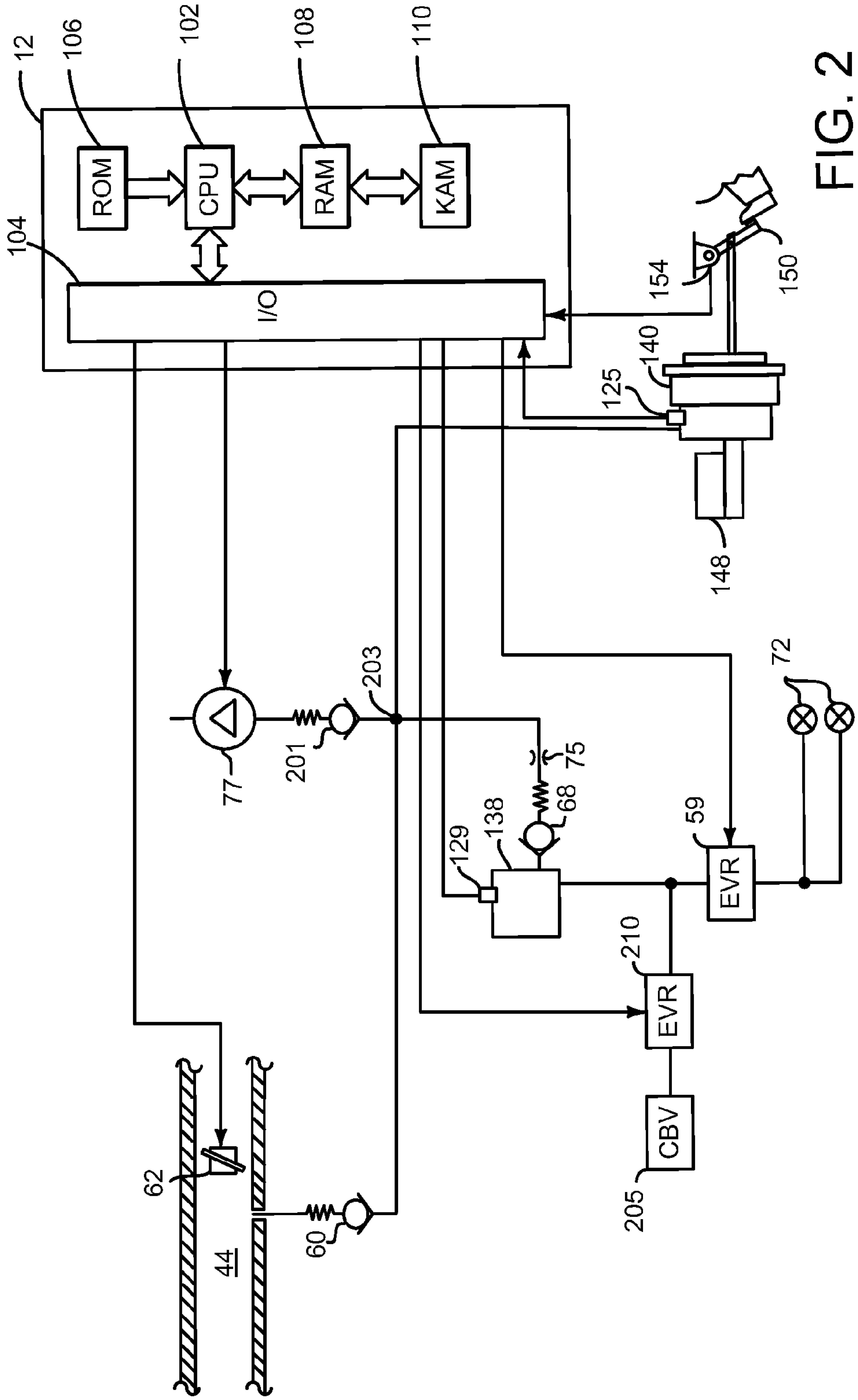
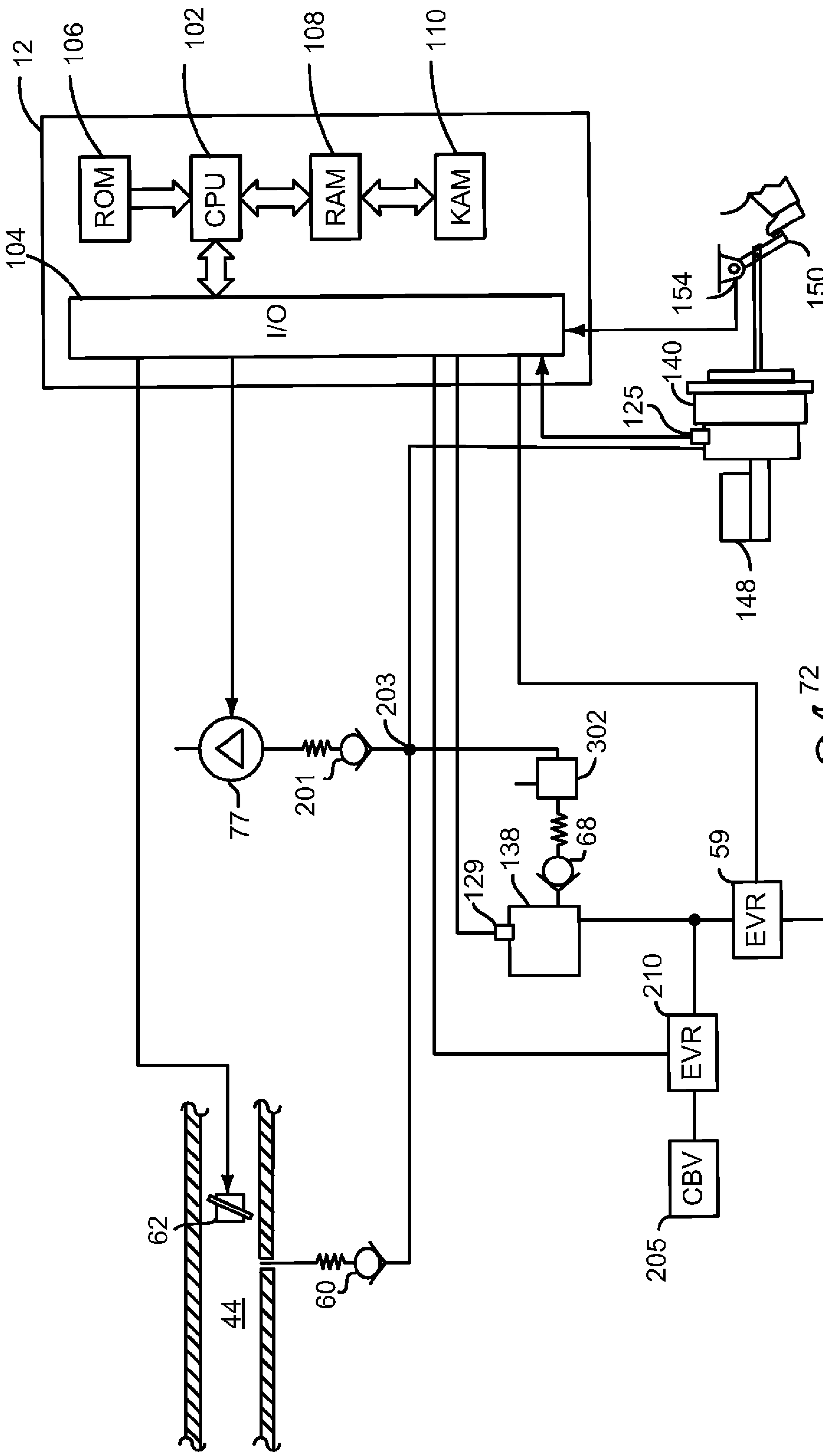

12
106
102
108
110
ROM
CPU
RAM
KAM
104
I/O
154
150
140
125
148
203
201
77
75
68
138
129
59
EVR
72
210
EVR
CBV
205
62
60
44

FIG. 2



12
106
102
108
110
104
ROM
CPU
RAM
KAM
I/O
154
150
140
125
148
203
302
77
201
68
138
129
59
EVR
72
210
EVR
CBV
205
62
60
44

FIG. 3

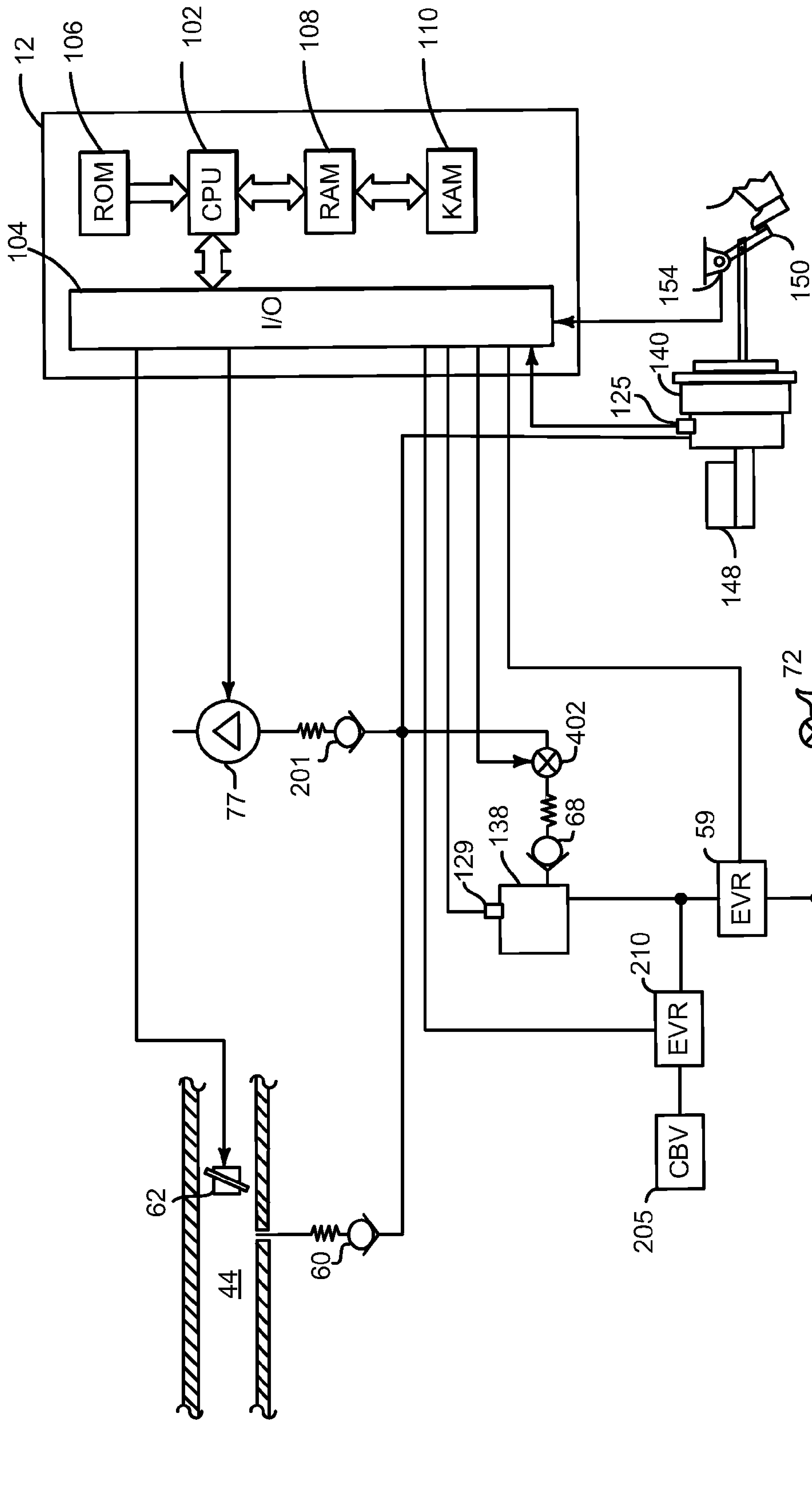
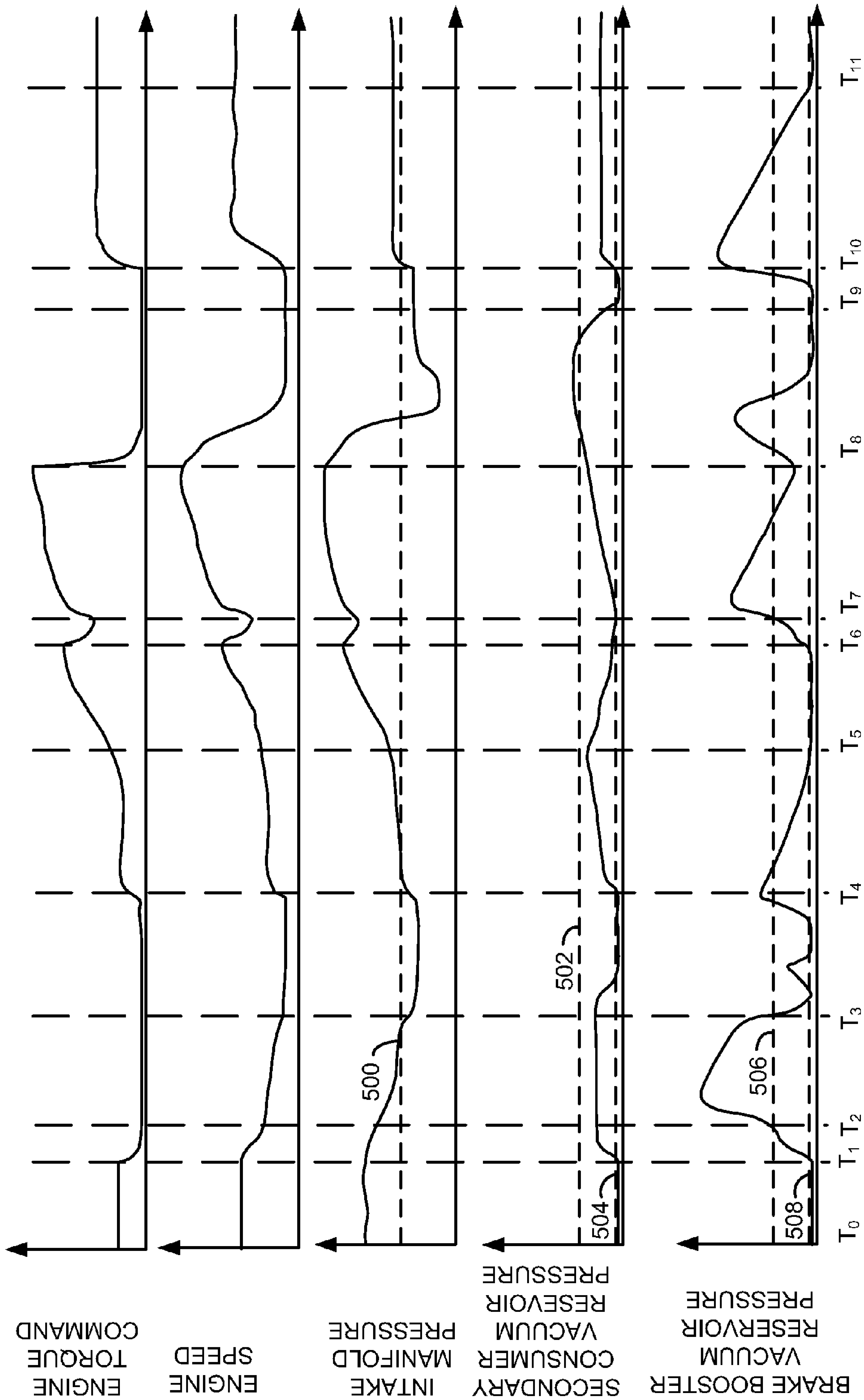

12
106
102
108
110
ROM
CPU
RAM
KAM
104
I/O
154
150
140
125
148
72
402
201
77
68
138
129
59
EVR
210
EVR
CBV
205
62
60
44

FIG. 4



ENGINE TORQUE COMMAND
ENGINE SPEED
INTAKE MANIFOLD PRESSURE
SECONDARY CONSUMER VACUUM RESERVOIR PRESSURE
BRAKE BOOSTER VACUUM RESERVOIR PRESSURE
500
502
504
506
508
T_0
T_1
T_2
T_3
T_4
T_5
T_6
T_7
T_8
T_9
T_{10}
T_{11}

FIG. 5

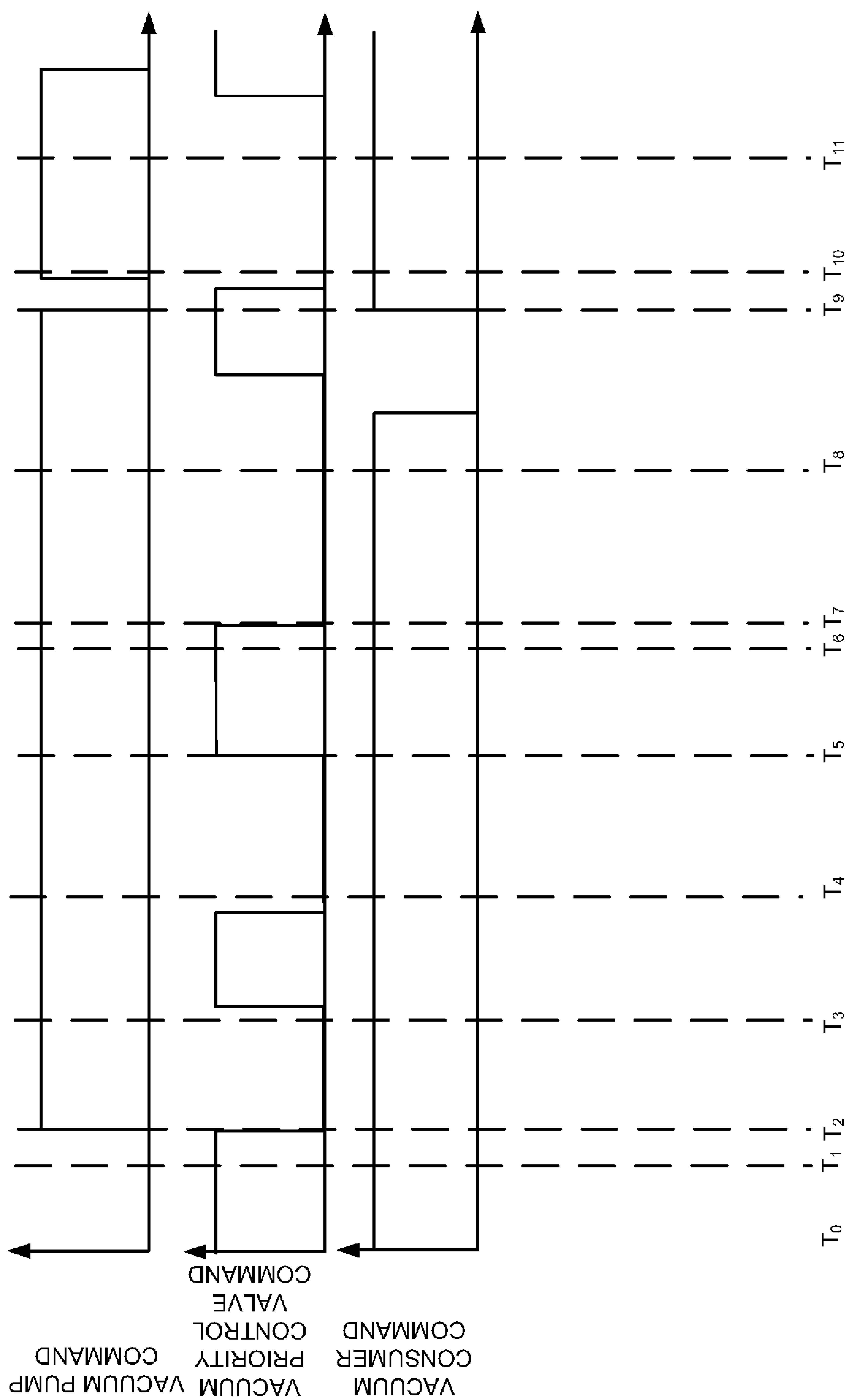

VACUUM PUMP COMMAND
VACUUM PRIORITY CONTROL VALVE COMMAND
VACUUM CONSUMER COMMAND
T_0
T_1
T_2
T_3
T_4
T_5
T_6
T_7
T_8
T_9
T_{10}
T_{11}

FIG. 6

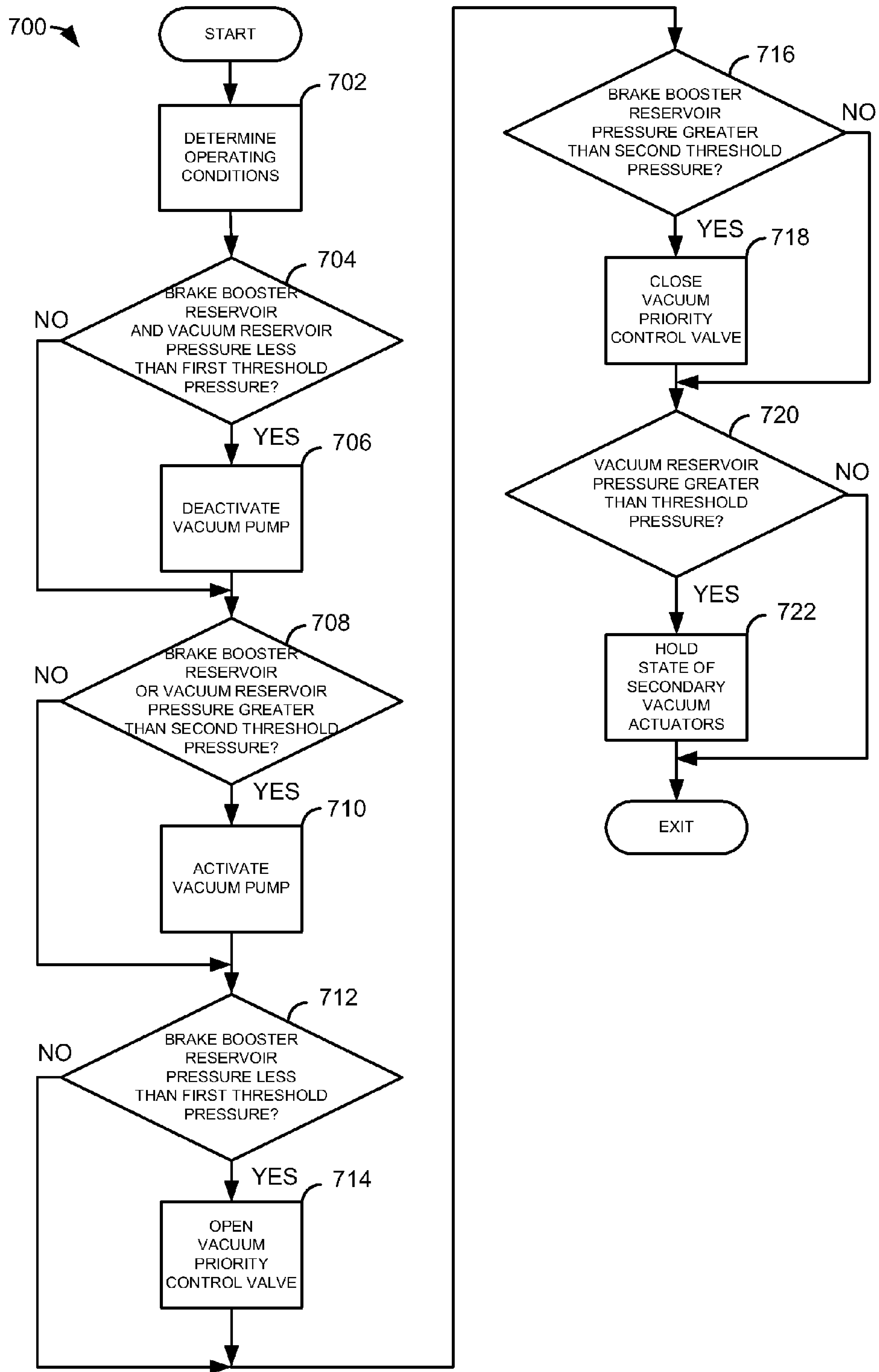

700
START
702
DETERMINE OPERATING CONDITIONS
704
BRAKE BOOSTER RESERVOIR AND VACUUM RESERVOIR PRESSURE LESS THAN FIRST THRESHOLD PRESSURE?
NO
YES
706
DEACTIVATE VACUUM PUMP
708
BRAKE BOOSTER RESERVOIR OR VACUUM RESERVOIR PRESSURE GREATER THAN SECOND THRESHOLD PRESSURE?
NO
YES
710
ACTIVATE VACUUM PUMP
712
BRAKE BOOSTER RESERVOIR PRESSURE LESS THAN FIRST THRESHOLD PRESSURE?
NO
YES
714
OPEN VACUUM PRIORITY CONTROL VALVE
716
BRAKE BOOSTER RESERVOIR PRESSURE GREATER THAN SECOND THRESHOLD PRESSURE?
NO
YES
718
CLOSE VACUUM PRIORITY CONTROL VALVE
720
VACUUM RESERVOIR PRESSURE GREATER THAN THRESHOLD PRESSURE?
NO
YES
722
HOLD STATE OF SECONDARY VACUUM ACTUATORS
EXIT

FIG. 7

METHOD AND SYSTEM FOR PRIORITIZING VEHICLE VACUUM

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 13/050,700, "METHOD AND SYSTEM FOR PRIORITIZING VEHICLE VACUUM," filed on Mar. 17, 2011, the entire contents of which are hereby incorporated by reference for all purposes.

BACKGROUND/SUMMARY

Vacuum may be used in vehicles to operate or to assist in the operation of vehicle brakes, ventilation systems, and other actuator devices. However, for engines that are boosted and that have relatively small displacement, it may be difficult to supply vacuum to all vacuum consumers (e.g., vacuum operated actuators such as turbocharger waste gate actuators, vehicle ventilation controls, and brake boosters) of the vehicle. For example, if an engine is operating at boosted conditions for a period of time, and at the same time vacuum is being consumed by vacuum consumers, the amount of vacuum in the vacuum system may be reduced to an extent that operation of one or more vacuum operated actuators may be degraded.

The inventors herein have recognized the above-mentioned disadvantages and have developed a vacuum prioritization method for a vehicle, comprising: providing vacuum via at least one vehicle vacuum source solely to a first actuator group when a pressure of a first vacuum reservoir is greater than a first threshold pressure; and providing vacuum via the at least one vehicle vacuum source to the first actuator group and a second actuator group when the pressure of the first vacuum reservoir is less than the first threshold pressure.

Operation of a vacuum system comprised of a plurality of vacuum consumers can be improved by prioritizing the use of vacuum between the various vacuum consumers. For example, assisting an operator to apply vehicle brakes via a brake booster may have higher vacuum use priority over operating a vehicle ventilation system. By making vacuum available to higher priority vacuum consumers and limiting vacuum available to lower priority vacuum consumers, higher priority vacuum consumers may operate for longer time periods when sources for producing vacuum may be limited. Further, the vacuum production capacity of vacuum sources may be applied solely to higher priority vacuum consumers rather than all vacuum consumers. In this way, operation of higher priority vacuum operated actuators may be improved.

The present description may provide several advantages. In particular, the approach may allow higher priority vacuum operated actuators to operate for longer periods of time when vacuum is not being generated by an engine of a vehicle. Further, the approach may improve the utility of vacuum produced during times of low vacuum availability. Further still, the approach can also limit the use of vacuum between secondary vacuum consumers so as to conserve vacuum between lower priority vacuum consumers.

The above advantages and other advantages, and features of the present description will be readily apparent from the following Detailed Description when taken alone or in connection with the accompanying drawings.

It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** shows a schematic depiction of an engine and vacuum system;

FIGS. **2-4** show schematic depictions of alternative vacuum systems;

FIGS. **5-6** show signals of interest during a prophetic vehicle drive cycle; and

FIG. **7** shows a high level flowchart of a method for prioritizing vacuum within a vehicle vacuum system.

DETAILED DESCRIPTION

The present description is related to providing vacuum to assists in actuator operation. FIG. **1** shows one example embodiment for providing vacuum to a vehicle vacuum system. FIGS. **2-4** show schematic depictions of alternative vacuum systems absent the detailed engine assembly shown in FIG. **1**. FIGS. **5** and **6** show prophetic signals of interest when operating a vehicle that has the capability of prioritizing vacuum of a vacuum system. FIG. **7** shows a method for prioritizing vacuum for a vehicle.

Referring to FIG. **1**, internal combustion engine **10**, comprising a plurality of cylinders, one cylinder of which is shown in FIG. **1**, is controlled by electronic engine controller **12**. Engine **10** includes combustion chamber **30** and cylinder walls **32** with piston **36** positioned therein and connected to crankshaft **40**. Combustion chamber **30** is shown communicating with intake manifold **44** and exhaust manifold **48** via respective intake valve **52** and exhaust valve **54**. Each intake and exhaust valve may be operated by an intake cam **51** and an exhaust cam **53**. Alternatively, one or more of the intake and exhaust valves may be operated by an electromechanically controlled valve coil and armature assembly. The position of intake cam **51** may be determined by intake cam sensor **55**. The position of exhaust cam **53** may be determined by exhaust cam sensor **57**.

Fuel injector **66** is shown positioned to inject fuel directly into cylinder **30**, which is known to those skilled in the art as direct injection. Alternatively, fuel may be injected to an intake port, which is known to those skilled in the art as port injection. Fuel injector **66** delivers liquid fuel in proportion to the pulse width of signal FPW from controller **12**. Fuel is delivered to fuel injector **66** by a fuel system (not shown) including a fuel tank, fuel pump, and fuel rail (not shown). Fuel injector **66** is supplied operating current from driver **95** which responds to controller **12**. In addition, intake manifold **44** is shown communicating with optional electronic throttle **62** which adjusts a position of throttle plate **64** to control air flow from intake boost chamber **46**.

Compressor **162** draws air from air intake **42** to supply boost chamber **46**. Exhaust gases spin turbine **164** which is coupled to compressor **162** via shaft **161**. Vacuum operated waste gate actuator **72** allows exhaust gases to bypass turbine **164** so that boost pressure can be controlled under varying operating conditions. Vacuum is supplied to waste gate actuator **72** from secondary vacuum consumer vacuum reservoir **138** or vacuum pump **77** via electronic vacuum regulator (EVR) **59**, check valve **61**, and check valve **63**. The

EVR may be a regulator that applies vacuum or venting based on a duty cycle applied to the regulator. Alternatively, the EVR may be comprised of two valves, one valve controlling the connection to vacuum and one controlling connection to vent. In this way, the EVR controls the position of the waste gate actuator.

Vacuum pump **77** may be selectively operated via a control signal from controller **12**. Check valve **61** allows air to flow to secondary vacuum consumer vacuum reservoir **138** from EVR **59** and limits air flow to EVR **59** from secondary vacuum consumer vacuum reservoir **138**. Check valve **63** allows air to flow to vacuum pump **77** from EVR **59** and limits air flow to EVR **59** from vacuum pump **77**. Secondary vacuum consumer vacuum reservoir **138** may be supplied vacuum from intake manifold **44** via check valve **60** or vacuum pump **77** via check valve **68** and orifice **75**. Orifice **75** may be used to restrict air flow from reservoir **138**. If reservoir **138** is restricted in this way, check valve **63** gives EVR **59** immediate access to any available vacuum source. Check valve **60** allows air to flow from secondary vacuum consumer vacuum reservoir **138** to intake manifold **44** and limits air flow from intake manifold **44** to secondary vacuum consumer vacuum reservoir **138**. Orifice **75** limits air flow from secondary vacuum consumer vacuum reservoir **138** to vacuum pump **77** so that brake booster **140** may be supplied a higher fraction of vacuum produced by vacuum pump **77**. Check valve **68** allows air to flow from secondary vacuum consumer vacuum reservoir **138** to vacuum pump **77** and limits air flow from vacuum pump **77** to secondary vacuum consumer vacuum reservoir **138**.

Brake booster **140**, including a brake booster reservoir, may be supplied vacuum from intake manifold **44** via check valve **73**. Check valve **73** allows air to flow to intake manifold **44** from brake booster **140** and limits air flow to brake booster **140** from intake manifold **44**. Check valves **73** and **60** accommodate fast pull down of the reservoir pressures when reservoir (e.g., **138** and **140**) pressure is relatively high and intake manifold pressure is low. Brake booster **140** may also be supplied vacuum from vacuum pump **77** via check valve **69**. Check valve **69** allows air to flow to vacuum pump **77** from brake booster **140** and limits air flow to brake booster **140** from vacuum pump **77**. Check valve **63** may be configured to open at a higher differential pressure than check valve **69** so that the brake booster is supplied vacuum before EVR **59**. Thus, the check valves may also be selected to prioritize vacuum provided from vacuum sources to primary and secondary vacuum consumers.

Secondary vacuum consumer vacuum reservoir **138** may also provide vacuum to other secondary vacuum consumers (e.g., heating and ventilation actuators, driveline actuators such as four wheel drive actuators, fuel vapor purging systems, engine crankcase ventilation, and fuel system leak testing systems). Brake booster **140** may include an internal vacuum reservoir, and it may amplify force provided by foot **152** via brake pedal **150** to master cylinder **148** for applying vehicle brakes (not shown).

Distributorless ignition system **88** provides an ignition spark to combustion chamber **30** via spark plug **92** in response to controller **12**. Universal Exhaust Gas Oxygen (UEGO) sensor **126** is shown coupled to exhaust manifold **48** upstream of catalytic converter **70**. Alternatively, a two-state exhaust gas oxygen sensor may be substituted for UEGO sensor **126**.

Converter **70** can include multiple catalyst bricks, in one example. In another example, multiple emission control devices, each with multiple bricks, can be used. Converter **70** can be a three-way type catalyst in one example.

Controller **12** is shown in FIG. **1** as a conventional microcomputer including: microprocessor unit **102**, input/output ports **104**, read-only memory **106**, random access memory **108**, keep alive memory **110**, and a conventional data bus. Controller **12** commands EVR **59** among other actuators. Controller **12** is shown receiving various signals from sensors coupled to engine **10**, in addition to those signals previously discussed, including: engine coolant temperature (ECT) from temperature sensor **112** coupled to cooling sleeve **114**; a position sensor **134** coupled to an accelerator pedal **130** for sensing accelerator position adjusted by foot **132**; a position sensor **154** coupled to brake pedal **150** for sensing brake pedal position; a knock sensor for determining ignition of end gases (not shown); a measurement of engine manifold pressure (MAP) from pressure sensor **121** coupled to intake manifold **44**; a measurement of boost pressure from pressure sensor **122** coupled to boost chamber **46**; brake booster reservoir pressure from pressure sensor **125**, vacuum reservoir pressure from pressure sensor **129**; an engine position sensor from a Hall effect sensor **118** sensing crankshaft **40** position; a measurement of air mass entering the engine from sensor **120** (e.g., a hot wire air flow meter); and a measurement of throttle position from sensor **58**. Barometric pressure may also be sensed (sensor not shown) for processing by controller **12**. In a preferred aspect of the present description, engine position sensor **118** produces a predetermined number of equally spaced pulses every revolution of the crankshaft from which engine speed (RPM) can be determined.

In some embodiments, the engine may be coupled to an electric motor/battery system in a hybrid vehicle. The hybrid vehicle may have a parallel configuration, series configuration, or variation or combinations thereof. Further, in some embodiments, other engine configurations may be employed, for example a diesel engine.

During operation, each cylinder within engine **10** typically undergoes a four stroke cycle: the cycle includes the intake stroke, compression stroke, expansion stroke, and exhaust stroke. During the intake stroke, generally, the exhaust valve **54** closes and intake valve **52** opens. Air is introduced into combustion chamber **30** via intake manifold **44**, and piston **36** moves to the bottom of the cylinder so as to increase the volume within combustion chamber **30**. The position at which piston **36** is near the bottom of the cylinder and at the end of its stroke (e.g. when combustion chamber **30** is at its largest volume) is typically referred to by those of skill in the art as bottom dead center (BDC). During the compression stroke, intake valve **52** and exhaust valve **54** are closed. Piston **36** moves toward the cylinder head so as to compress the air within combustion chamber **30**. The point at which piston **36** is at the end of its stroke and closest to the cylinder head (e.g. when combustion chamber **30** is at its smallest volume) is typically referred to by those of skill in the art as top dead center (TDC). In a process hereinafter referred to as injection, fuel is introduced into the combustion chamber. In a process hereinafter referred to as ignition, the injected fuel is ignited by known ignition means such as spark plug **92**, resulting in combustion. During the expansion stroke, the expanding gases push piston **36** back to BDC. Crankshaft **40** converts piston movement into a rotational torque of the rotary shaft. Finally, during the exhaust stroke, the exhaust valve **54** opens to release the combusted air-fuel mixture to exhaust manifold **48** and the piston returns to TDC. Note that the above is described merely as an example, and that intake and exhaust valve opening and/or closing timings may vary, such as to provide positive or negative valve overlap, late intake valve closing, or various other examples.

FIGS. **2-4** are alternative examples of systems for prioritizing use of vacuum between multiple vacuum consumers. For the sake of simplicity and brevity, selected engine components shown in FIG. **1** are omitted from FIGS. **2-4**. However, the systems of FIGS. **2-4** are anticipated to operate with an engine as shown in FIG. **1**. Further, components shown in FIGS. **2-4** having the same numerical identifiers as shown in FIG. **1** are to be considered to be the same elements as shown in FIG. **1**. Therefore, the description of such elements is omitted for the sake of brevity. Likewise, the components of FIGS. **3** and **4** that are illustrated with the same numerical identifiers shown in FIG. **2** are to be considered to be the same elements shown in FIG. **2**.

Referring now to FIG. **2**, an alternative example system for prioritizing vacuum within a vehicle vacuum system is shown. Vacuum may be supplied to a vacuum reservoir in brake booster **140** and secondary vacuum consumer vacuum reservoir **138** via intake manifold **44** and/or vacuum pump **77**. Check valve **201** allows air to flow from a vacuum reservoir in brake booster **140** or from secondary vacuum consumer vacuum reservoir **138**. Check valve **201** limits air flow from vacuum pump **77** to secondary vacuum consumer vacuum reservoir **138** and the vacuum reservoir in brake booster **140**. When a pressure of intake manifold **44** is lower than a pressure of the vacuum reservoir in brake booster **140** or a pressure in secondary vacuum consumer vacuum reservoir **138**, check valve **60** allows air to flow into intake manifold **44** from one of secondary vacuum consumer vacuum reservoir **138** and the vacuum reservoir of brake booster **140**.

Check valve **60**, check valve **201**, the vacuum reservoir in brake booster **140**, and secondary vacuum consumer vacuum reservoir **138** are connected at pressure node **203**. Further, the vacuum reservoir in brake booster **140** is directly connected to pressure node **203** without any intermediate devices. Consequently, the pressure in the vacuum reservoir of brake booster **140** is substantially equivalent to the pressure at pressure node **203**. In contrast, a pressure differential may exist between pressure node **203** and secondary vacuum consumer vacuum reservoir **138** since pressure node **203** and secondary vacuum consumer vacuum reservoir **138** are separated by orifice **75** and check valve **68**.

Orifice **75** and check valve **68** act to prioritize the use of vacuum that may be provided via vacuum pump **77** and intake manifold **44**. In particular, the amount of vacuum available to evacuate air from secondary vacuum consumer vacuum reservoir **138** is limited by the air flow through orifice **75**. Orifice **75** is sized such that no matter the pressure differential across orifice **75**, the flow rate through orifice **75** is less than half the air flow capacity of vacuum pump **77** when vacuum pump **77** is operating. Consequently, the vacuum reservoir of brake booster **140** has access to a higher percentage of vacuum supplied to pressure node **203** via vacuum pump **77** than does vacuum consumer vacuum reservoir **138**. Similarly, orifice **75** limits the rate of pressure reduction of secondary vacuum consumer vacuum reservoir **138** when intake manifold **44** is at a lower pressure than pressure node **203**. In this way, orifice **75** makes the vacuum reservoir in brake booster **140** a higher priority user of vacuum provided by vacuum pump **77** and intake manifold **44**.

Controller **12** also can set the priority of vacuum use from secondary vacuum consumer vacuum reservoir **138**. For example, if the pressure of secondary vacuum consumer vacuum reservoir **138** is greater than a first threshold pressure and less than a second threshold pressure, controller **12** may allow EVR **210** and EVR **59** to adjust pressures supplied to turbocharger compressor bypass valve (CBV) **205** and waste gate actuators **72**. EVR **210** may be integrated with CBV **205** to provide an electrically commanded vacuum operated CBV. In one example, the CBV may include a piloted valve so that the electrical actuation force is amplified pneumatically. On the other hand, if the pressure of secondary vacuum consumer vacuum reservoir **138** is greater than the first and second threshold pressures, controller **12** may allow EVR **210** to adjust pressure supplied to CBV **205** while holding the present amount of vacuum supplied to waste gate actuators **72** to hold the state of turbocharger waste gates.

Referring now to FIG. **3**, an alternative example system for prioritizing vacuum within a vehicle vacuum system is shown. The example system of FIG. **3** is the same as the system described in FIG. **2** except that the system of FIG. **3** includes a pneumatic valve **302** rather than orifice **75**. Further, controller **12** can prioritize the use of vacuum from secondary vacuum consumer vacuum reservoir **138** as described in FIG. **2**.

Pneumatic valve **302** is referenced to atmospheric pressure and allows air flow from secondary vacuum consumer vacuum reservoir **138** to pressure node **203** when pressure at node **203** is less than a predetermined pressure. Thus, the vacuum reservoir of brake booster **140** is allocated use of vacuum without interference from secondary vacuum consumer vacuum reservoir **138**, EVR **210**, and EVR **59** when vacuum is limited at pressure node **203**. In particular, pressure in brake booster **140** may be reduced while pressure at the vacuum consumer vacuum reservoir **138** stays constant or increases. In this way, pneumatic valve **302** controls the priority of vacuum use within the vacuum system. In particular, brake booster **140** has higher priority for vacuum that is produced via vacuum pump **77** and intake manifold **44** when pressure at pressure node **203** is greater than a predetermined value. It should be noted that the pressure threshold at pressure node **203** may be adjusted for different operating conditions such as different ambient barometric pressures.

Referring now to FIG. **4**, an alternative example system for prioritizing vacuum with a vehicle vacuum system is shown. The example system of FIG. **4** is the same as the system described in FIG. **2** except that the system of FIG. **4** includes an electrically controlled valve **402** rather than orifice **75**. Further, controller **12** can prioritize the use of vacuum from secondary vacuum consumer vacuum reservoir **138** as described in FIG. **2**.

Electrically actuated valve **402** may be selectively operated via an electrical signal from controller **12**. In one example, controller **12** includes instructions for closing electrically actuated valve **402** when a pressure in the vacuum reservoir of brake booster **140** is greater than a predetermined amount. In other examples, electrically actuated valve **402** may be closed when a rate of pressure change within the vacuum reservoir of brake booster **140** exceeds a predetermined amount. Thus, similar to the pneumatic valve illustrated in FIG. **3**, the electrically actuated valve of FIG. **4** can provide priority of vacuum supplied via vacuum pump **77** and intake manifold **44** to brake booster **140** during conditions when pressure at pressure node **203** and the vacuum reservoir of brake booster **140** is greater than a threshold level. Further, controller **12** may include instructions for adjusting the pressure threshold at which electrically actuated valve **402** closes.

In an alternative example, the system of FIG. **4** includes a check valve positioned between the intake manifold **44** and reservoir **138**. The check valve is biased to allow for fast pressure pull down in the case where intake manifold pressure is low.

Referring now to FIGS. **5** and **6**, simulated signals of interest during engine operation are shown. Vertical markers T_0-T_{11} identify particular times of interest during the operating sequence. The signals of FIG. **5** and the signals of FIG. **6** are signals of a same operating sequence. Thus, times T_0-T_{11} of FIG. **5** and FIG. **6** are the identical times. In addition, the signals of FIGS. **5-6** may be provided by the system shown in FIG. **4**.

The first plot from the top of FIG. **5** shows an engine torque command signal versus time. Time starts at the left side of the plot and increases to the right. The engine torque command signal is at its lowest value at the bottom of the plot and it increases in magnitude toward the top of the plot. A lower torque command provides for a lower engine output torque. A higher torque command provides for a higher engine output torque.

The second plot from the top of FIG. **5** shows engine speed versus time. Time starts at the left side of the plot and increases to the right. Engine speed is at its lowest value at the bottom of the plot and increases toward the top of the plot.

The third plot from the top of FIG. **5** shows engine intake manifold pressure versus time (e.g., intake manifold **44** of FIG. **4**). Time starts at the left side of the plot and increases to the right. Engine intake manifold pressure increases in the direction of the Y-axis arrow. Horizontal marker **500** represents atmospheric pressure in the third plot. Thus, when manifold pressure is above marker **500**, the intake manifold is at a positive pressure. When manifold pressure is below marker **500** the intake manifold is at a vacuum.

The fourth plot from the top of FIG. **5** shows secondary vacuum consumer vacuum reservoir pressure versus time (e.g., secondary vacuum consumer vacuum reservoir **138** of FIG. **4**). Time starts at the left side of the plot and increases to the right. Horizontal marker **502** represents a second threshold level of vacuum reservoir pressure. Horizontal marker **504** represents a first threshold level of vacuum reservoir pressure. Vacuum reservoir vacuum is at a higher level of vacuum at the bottom of the plot.

The fifth plot from the top of FIG. **5** shows brake booster vacuum reservoir pressure versus time (e.g., brake booster **140** of FIG. **4**). Time starts at the left side of the plot and increases to the right. Horizontal marker **506** represents a second threshold level of vacuum reservoir pressure. Horizontal marker **508** represents a first threshold level of vacuum reservoir pressure. Brake booster vacuum reservoir vacuum is at a higher level of vacuum at the bottom of the plot.

The first plot from the top of FIG. **6** shows vacuum pump activation command. The vacuum pump (e.g., vacuum pump **77** of FIG. **4**) is commanded on when the vacuum pump activation command is near the top of the first plot. The vacuum pump is commanded off when the vacuum pump activation command is near the bottom of the first plot.

The second plot from the top of FIG. **6** shows a vacuum priority control valve command. The vacuum priority control valve (e.g., electrically actuated valve **402** of FIG. **4**) is commanded open when the vacuum priority control valve command is near the top of the second plot. The vacuum priority control valve is commanded closed when the vacuum priority control valve is command is near the bottom of the second plot.

The third plot from the top of FIG. **6** shows a vacuum consumer command. The vacuum consumer command represents a signal for limiting use of vacuum by vacuum consumers other than the primary (e.g., brake booster and other selected vacuum consumers) vacuum consumers. Vacuum consumers may include but are not limited to waste gate actuators, heating and ventilation actuators, fuel vapor purging systems, drivetrain actuators, engine crankcase ventilation, and leak check systems. When the vacuum consumer command is near the top of the plot, vacuum consumers may use as much vacuum as they desire. When the vacuum consumer command is near the bottom of the plot, selected vacuum consumers may be held in their present operating state so that vacuum is conserved.

It should be noted that intake manifold pressure and vacuum reservoir pressure are not plotted to the same scale. For example, the units of the Y axis of the intake manifold pressure plot are not equivalent to the units of the Y axis of the vacuum reservoir plot.

At time T_0, the engine is operating at a low engine torque (e.g., 20% of wide-open-throttle (WOT)). Further, the engine speed is at a medium engine speed (e.g., 2500 RPM), the intake manifold pressure is above atmospheric pressure, pressure in the secondary vacuum consumer vacuum reservoir is less than a first threshold pressure **504**, brake booster vacuum reservoir pressure is less than a first threshold pressure **508**, the vacuum pump command is off, the vacuum priority control valve is commanded open, and the vacuum consumer command is at a high level so that all vacuum consumers may have access to vacuum.

The vacuum pump command is shown commanding the vacuum pump off because both the secondary vacuum consumer vacuum reservoir and the brake booster vacuum reservoir pressure are less than the first pressure thresholds **504** and **508** respectively. The vacuum priority control valve signal is shown commanding the vacuum priority valve to an open position so that vacuum provided by the intake manifold **44** and the vacuum pump **77** is available throughout the vacuum system. The vacuum consumer command is at a high level so that all vacuum consumers may have access to system vacuum.

At time T_1, the engine torque command is reduced from a low level. In some examples, when the engine torque demand is reduced from a low level engine torque demand at relatively low engine speed, the controller reduces intake manifold pressure at a low rate so that the torque reduction is less noticeable to the driver. During such conditions it may take more time for pressure in the intake manifold to fall below atmospheric pressure. The engine speed begins to decrease at T_1 since less engine torque is available to rotate the engine. Intake manifold pressure also begins to decrease since less air is needed for a reduced engine torque demand. The secondary vacuum consumer vacuum reservoir pressure begins to increase as vacuum is used to adjust the turbocharger waste gate. In addition, the secondary vacuum consumer vacuum reservoir pressure increase may be related to vacuum consumption by other vacuum consumers (e.g., ventilation system, drivetrain actuators, and CBV actuators). Pressure in the brake booster vacuum reservoir begins to increase shortly after time T_1 in response to depression of a brake pedal, for example. The vacuum pump command remains such that the vacuum pump is commanded to an off state. The vacuum priority control valve is commanded to an open state so that air can flow to vacuum sources (e.g., vacuum pump and intake manifold) from secondary vacuum consumers (e.g., vacuum consumers other than the brake booster) if pressure at the vacuum sources is lower than at the secondary vacuum consumer vacuum reservoir (e.g., **138** of FIG. **4**).

At time T_2, the engine torque command remains low and the engine speed continues to decrease. Further, intake manifold pressure continues to decrease as air is pumped from the engine intake manifold. Pressure in the secondary vacuum consumer vacuum reservoir continues to increase at a relatively slow rate. Pressure in the brake booster vacuum reservoir increases more rapidly and to a higher level as the break pedal is released. In particular, pressure in the brake booster reservoir increases to a level greater than the second pressure threshold **506**. A brake booster vacuum reservoir pressure greater than the second pressure threshold **506** causes a controller (e.g., controller **12** of FIG. **4**) to command the vacuum pump on. Further, the controller commands the vacuum priority control valve closed so that vacuum from the vacuum pump and the intake manifold is available to only higher priority vacuum consumers (e.g., brake booster). Activating the vacuum pump begins to reduce pressure in the brake booster vacuum reservoir. The vacuum consumer command remains at a high level indicating that vacuum in the secondary vacuum consumer vacuum reservoir is at a level sufficient to continue supplying vacuum to secondary vacuum consumers.

It should be mentioned that in all the examples mentioned, the higher priority vacuum consumers may be comprised of a group of vacuum consumers selected based on system requirements. In some examples, the higher priority group of vacuum consumers may be comprised of two or more vacuum consumers (e.g., brake booster and waste gate actuators). In other examples, the higher priority group of vacuum consumers may be comprised of a single vacuum consumer (e.g., brake booster).

At time T_3, the engine torque command and engine speed are at relatively low levels. Further, the intake manifold pressure has been reduced to a pressure less than atmospheric pressure. In some examples, pressure in the engine intake manifold may be decreased by increasing engine speed, shifting gears, throttling the engine, and/or discarding engine loads in response to a pressure in the vacuum system greater than a predetermined pressure. When the intake manifold pressure is less than the pressure in the vacuum system at the vacuum reservoir in the brake booster, a check valve opens and allows air to flow into the intake manifold, thereby lowering pressure in the vacuum reservoir in the brake booster. As such, the pressure in the brake booster vacuum reservoir decreases at a more rapid rate since air flows from the brake booster vacuum reservoir to the vacuum pump and the intake manifold. Since the engine has a large displacement relative to the vacuum pump, it is possible for the engine to draw air at much higher rates than the vacuum pump during some conditions. The vacuum pump remains on at time T_3, and the vacuum priority control valve remains closed so that vacuum from the intake manifold and the vacuum pump is available solely to primary vacuum consumers. However, shortly after time T_3, the vacuum priority control valve is commanded to an open state so that vacuum provided by the intake manifold and the vacuum pump is made available to secondary vacuum consumers. The vacuum priority control valve is commanded open in response to pressure in the brake booster vacuum reservoir reaching the first pressure threshold **508**. When the vacuum priority control valve is opened, pressure in the secondary vacuum consumer vacuum reservoir which supplies vacuum to secondary vacuum consumers is lowered since vacuum from the intake manifold and the vacuum pump is made available to the secondary vacuum consumer vacuum reservoir. Shortly before time T_4, the vehicle brake is released causing pressure in the brake booster vacuum reservoir to increase above the second pressure threshold **506**. The vacuum priority control valve closes in response to pressure in the brake booster vacuum reservoir exceeding the second pressure threshold **506**.

At time T_4, the engine torque command increases and engine speed follows the increase in engine torque. Intake manifold pressure also increases in response to the greater torque demand. Pressure in the brake booster vacuum reservoir is gradually reduced by the activated vacuum pump. Since pressure in the intake manifold is greater than the pressure in the brake booster, the intake manifold does not reduce brake booster vacuum reservoir pressure. Pressure in the secondary vacuum consumer vacuum reservoir gradually increases since the secondary vacuum consumer vacuum reservoir is isolated from intake manifold and vacuum pump vacuum sources via the vacuum priority control valve and since vacuum within the secondary vacuum consumer vacuum reservoir is consumed by secondary vacuum consumers (e.g., waste gate actuators, ventilation controls, and CBV). The vacuum consumer command remains at a high level since vacuum in the secondary vacuum consumer vacuum reservoir remains below the second vacuum reservoir pressure threshold **502**. Therefore, all secondary consumers have access to vacuum in the secondary vacuum consumer vacuum reservoir.

At time T_5, pressure in the brake booster vacuum reservoir is reduced to less than the first brake booster vacuum reservoir pressure threshold. In addition, the vacuum priority control valve is commanded to an open state so that the secondary vacuum consumer vacuum reservoir can be supplied vacuum from the vacuum pump and intake manifold. Pressure in the secondary vacuum consumer vacuum reservoir is shown gradually increasing until the vacuum priority control valve is opened at time T_5.

At time T_6, the engine torque command and engine speed are briefly reduced. The intake manifold pressure is also reduced as air is pumped from the intake manifold; however, pressure in the intake manifold remains above atmospheric pressure so that vacuum may not be supplied by the intake manifold. Pressure in the secondary vacuum consumer vacuum reservoir is near the first secondary vacuum consumer vacuum reservoir pressure threshold but does not fall below the first secondary vacuum consumer vacuum reservoir pressure threshold. Further, pressure in the brake booster vacuum reservoir increases as the vehicle brake is applied.

At time T_7, the vehicle brake pedal is released and the engine torque command is increased. Engine speed increases with the increased engine torque demand and intake manifold pressure also increases with the increased engine torque demand. Pressure in the brake booster vacuum reservoir increases to a level above the second brake booster vacuum reservoir pressure threshold when the brake pedal is released. Further, the vacuum priority control valve is commanded to a closed position so that vacuum from the vacuum pump and intake manifold is available solely to primary vacuum consumers. Pressure in the secondary vacuum consumer vacuum reservoir begins to increase after time T_7 in response to secondary vacuum consumers using vacuum from the secondary vacuum consumer vacuum reservoir. Pressure in the brake booster vacuum reservoir increases after the vehicle brake is released and then begins to decrease as the vacuum pump evacuates air from the brake booster vacuum reservoir.

At time T_8, the engine torque command is reduced relatively quickly from a higher engine torque demand. The engine speed also begins to decline after the engine torque demand is reduced. When engine torque is reduced during such conditions, the engine controller can evacuate air from the intake manifold at a higher rate so that the vehicle decelerates at a desired rate. In this example, the intake manifold pressure is initially reduced at a first rate and then further reduced at a second rate when application of the vehicle brake causes pressure in the brake booster vacuum reservoir to increase to a level above the second brake booster vacuum reservoir pressure threshold at **506**. Pressure in the brake booster vacuum reservoir is reduced by the vacuum pump, but the rate of pressure reduction within the brake booster increases when pressure in the intake manifold falls below brake booster pressure. Pressure within the secondary vacuum consumer vacuum reservoir continues to increase at time T_8 since vacuum consumption by secondary vacuum continues and since the vacuum priority control valve remains in a closed position.

Between time T_8 and time T_9, pressure in the secondary vacuum consumer vacuum reservoir increases to a level greater than the second secondary vacuum consumer vacuum reservoir pressure threshold. During such conditions, vacuum use for secondary vacuum consumers that may be isolated from vacuum sources via the vacuum priority control valve may be prioritized by the vacuum controller. In one example, secondary vacuum consumers that have less priority over other secondary vacuum consumers are held in their present operating state to conserve vacuum in the vacuum reservoir. The higher priority secondary vacuum consumers may continue to use vacuum from the secondary vacuum consumer vacuum reservoir. The vacuum consumer command goes to a low state to indicate that lower priority vacuum consumers within the secondary vacuum consumer group are to remain or transition to a low vacuum use state.

Pressure in the brake booster vacuum reservoir also increases just after time T_8 in response to application of vehicle brakes, and then pressure decreases to a level below the first brake booster vacuum reservoir pressure threshold as the pressure is reduce via the vacuum pump and the intake manifold. As a result, the vacuum priority control valve is opened so that the secondary vacuum consumer vacuum reservoir and secondary vacuum consumers may be put in communication with intake manifold and vacuum pump vacuum sources. Opening the vacuum priority control valve allows pressure in the secondary vacuum consumer vacuum reservoir to fall below the second vacuum reservoir pressure threshold so that vacuum is not prioritized between vacuum consumers of the secondary vacuum consumer group.

At time T_9, pressure in the secondary vacuum consumer vacuum reservoir is reduced to a level less than the first secondary vacuum consumer vacuum reservoir pressure threshold. Further, since pressure in the brake booster vacuum reservoir is less than the first brake booster vacuum reservoir pressure threshold. Consequently, the vacuum pump is deactivated to reduce engine fuel consumption. In addition, the vacuum consumer command is returned to a high level at time T_9.

Shortly after time T_9, the vehicle brakes are released and pressure within the brake booster vacuum reservoir increases to a level above the second brake booster vacuum reservoir pressure threshold. Therefore, in response to the pressure in the brake booster vacuum reservoir being above the second brake booster vacuum threshold, the vacuum priority control valve commands the vacuum priority control valve to a closed position and the vacuum pump is reactivated. As such, the secondary vacuum consumers are isolated from the intake manifold and vacuum pump vacuum sources.

At time T_{10}, engine torque is increased and engine speed increases with the increased engine torque demand. Intake manifold pressure also increases so that the engine torque demand may be met. Pressure in the vacuum reservoir also increases as secondary vacuum consumers such as waste gate actuators consume vacuum from the vacuum reservoir.

At time T_{11}, pressure in the brake booster vacuum reservoir has been reduced by the vacuum pump to less than the first brake booster vacuum reservoir pressure threshold. Consequently, the vacuum priority control valve command goes to a high level so that secondary vacuum consumers may be put in communication with intake manifold and vacuum pump vacuum sources.

Thus, FIGS. **5** and **6** show signals from an example operating sequence. The signals of FIGS. **5** and **6** may be provided by the method of FIG. **7** executed within controller **12** of FIG. **4**. The systems of FIGS. **1-3** may have signals similar to those of FIGS. **5** and **6** with the exception of the vacuum priority control valve command.

Referring now to FIG. **7**, a method for prioritizing vacuum within a vehicle vacuum system is shown. The method of FIG. **7** may be executed by a controller **12** of FIGS. **1-4**.

At **702**, method **700** determines operating conditions. In one example, operating conditions may include but are not limited to engine speed, engine torque demand, secondary vacuum consumer vacuum reservoir pressure, brake booster vacuum reservoir pressure, intake manifold pressure, and ambient pressure. Method **700** proceeds to **704** after operating conditions are determined.

At **704**, method **700** judges whether or not brake booster vacuum reservoir and secondary vacuum consumer vacuum reservoir pressure are less than a first threshold pressure. In some examples, the first threshold pressure may vary with operating conditions. For example, the first threshold pressure may increase for decreasing ambient pressure. If method **700** judges that brake booster vacuum reservoir pressure and secondary vacuum consumer vacuum reservoir pressure are less than the first threshold pressure, method **700** proceeds to **706**. Otherwise, method **700** proceeds to **708**.

At **706**, method **700** deactivates a vacuum pump of the vacuum system. In one example, the vacuum pump may be deactivated via commanding a relay to an open state. Method **700** proceeds to **708** after the vacuum pump is deactivated.

At **708**, method **700** judges whether or not brake booster vacuum reservoir pressure or secondary vacuum consumer vacuum reservoir pressure are greater than a second threshold pressure. In some examples, the second threshold pressure may vary with operating conditions. For example, the second threshold pressure may increase for decreasing ambient pressure. If method **700** judges that brake booster vacuum reservoir pressure or secondary vacuum consumer vacuum reservoir pressure is greater than the second threshold pressure, method **700** proceeds to **710**. Otherwise, method **700** proceeds to **712**.

At **710**, method **710** activates the vacuum pump of the vacuum system. In one example, the vacuum pump may be activated by commanding a relay to a closed state. Method **700** proceeds to **712** after the vacuum pump is deactivated.

At **712**, method **700** judges whether or not brake booster vacuum reservoir pressure is less than a first brake booster vacuum reservoir threshold pressure. If so, method **700** proceeds to **714**. Otherwise, method **700** proceeds to **716**.

At **714**, method **700** opens a vacuum priority control valve. In one example, the vacuum priority control valve is placed in a conduit that couples the secondary vacuum consumer vacuum reservoir to the brake booster vacuum reservoir and the vacuum sources (e.g., vacuum pump and/or engine intake manifold). The system of FIG. **4** shows one example system configuration where vacuum priority control valve **402** controls air flow from the secondary vacuum consumer vacuum reservoir to the brake booster vacuum reservoir, intake manifold, and vacuum pump. The vacuum priority control valve may be opened via an electric signal. Method **700** proceeds to **716** after the vacuum priority control valve is opened.

At **716**, method **700** judges whether or not brake booster reservoir pressure is greater than a second threshold pressure. If so, method **700** proceeds to **718**. Otherwise, method **700** proceeds to **720**.

At **718**, method **700** closes the vacuum priority control valve to isolate the secondary vacuum consumers vacuum reservoir and secondary vacuum consumers from the vacuum sources and the brake booster vacuum reservoir. In one example, the vacuum priority control valve can be closed via an electrical signal from a controller (e.g., controller **12** of FIG. **4**). Method **700** proceeds to **720** after the vacuum priority control valve is closed.

At **720**, method **700** judges whether or not secondary vacuum consumer vacuum reservoir pressure is greater than a second threshold pressure. If so, method **700** proceeds to **722**. Otherwise, method **700** proceeds to exit.

At **722**, method **700** holds the state of selected secondary vacuum consumers or adjusts commands to reduce the rate vacuum is consumed by the selected secondary vacuum consumers. The selected secondary vacuum consumers may be a fraction of a group of secondary vacuum consumers. In one example, a group of secondary vacuum consumers is separated into a first and second group of vacuum consumers. The controller continues to adjust a first EVR regulating vacuum supplied to the first group of secondary vacuum consumers while the controller holds the state of a second EVR regulating vacuum supplied to the second group of vacuum consumers. In this way, the controller gives vacuum priority to the first group of vacuum consumers over the second group of vacuum consumers. Method **700** proceeds to exit after prioritizing vacuum use between groups of secondary vacuum consumers.

In an example where a normally open vacuum actuated waste gate is present, it may be desirable to keep the waste gate closed in case of high vacuum reservoir pressure because the waste gate readiness may be more important than fuel economy associated with opening the waste gate to prevent higher turbine speeds.

As will be appreciated by one of ordinary skill in the art, the methods described in FIG. **7** may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various steps or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the objects, features, and advantages described herein, but is provided for ease of illustration and description. Although not explicitly illustrated, one of ordinary skill in the art will recognize that one or more of the illustrated steps or functions may be repeatedly performed depending on the particular strategy being used.

This concludes the description. The reading of it by those skilled in the art would bring to mind many alterations and modifications without departing from the spirit and the scope of the description. For example, single cylinder, I2, I3, I4, I5, V6, V8, V10, V12 and V16 engines operating in natural gas, gasoline, diesel, or alternative fuel configurations could use the present description to advantage.

The invention claimed is:

1. A vacuum prioritization method for a vehicle, comprising:

providing vacuum via at least one vehicle vacuum source solely to a first actuator group when a pressure of a first vacuum reservoir is greater than a first threshold pressure;

providing vacuum via the at least one vehicle vacuum source to the first actuator group and a second actuator group when the pressure of the first vacuum reservoir is less than the first threshold pressure; and

supplying vacuum to the second actuator group via a second vacuum reservoir when the pressure in the first vacuum reservoir is greater than the first threshold pressure.

2. The vacuum prioritization method of claim **1**, where the at least one vehicle vacuum source includes an intake manifold of an engine and a vacuum pump or an ejector, where the first actuator group and second actuator group are comprised of vacuum operated actuators, and where the first vacuum reservoir is a brake booster reservoir.

3. The vacuum prioritization method of claim **2**, where the vacuum pump is selectively activated in response to the pressure of the first vacuum reservoir.

4. The vacuum prioritization method of claim **1**, where air flow between the first vacuum reservoir and the second vacuum reservoir is limited via an orifice or a valve that is controlled in response to the pressure of the first vacuum reservoir.

5. The vacuum prioritization method of claim **1**, further comprising holding the second actuator group in an operating state when the pressure in the first vacuum reservoir is greater than the first threshold pressure and when a pressure in the second vacuum reservoir is greater than a second threshold pressure.

6. The vacuum prioritization method of claim **1**, further comprising increasing an amount of vacuum supplied to the first vacuum reservoir via adjusting operation of an engine when the pressure of the first vacuum reservoir is greater than the first threshold pressure and when a torque demand of the engine is less than a threshold torque demand.

7. A system for providing vacuum for a vehicle, comprising:

a brake-booster vacuum reservoir;

a secondary vacuum reservoir;

a first vacuum source in communication with the brake-booster and secondary vacuum reservoirs;

a second vacuum source in communication with the brake-booster and secondary vacuum reservoirs; and

a device to provide priority to receive vacuum at the brake-booster vacuum reservoir over the secondary vacuum reservoir via the first vacuum source and the second vacuum source.

8. The system of claim **7**, where the device is an orifice positioned in a conduit at a location between the brake-booster vacuum reservoir and the secondary vacuum reservoir.

9. The system of claim **7**, where the device is a controller including instructions for prioritizing vacuum supplied via the first vacuum source and the second vacuum source to the brake-booster vacuum reservoir and the secondary vacuum reservoir.

10. The system of claim **9**, where the first vacuum source is an intake manifold of an engine, and further comprising additional instructions for decreasing a pressure of the intake manifold when a pressure of the brake-booster vacuum reservoir exceeds a first pressure while an engine torque demand is less than a first torque demand.

11. The system of claim **7**, where the device is a pneumatically controlled valve.

12. The system of claim **7**, where the second vacuum source is a vacuum pump or an ejector.

13. The system of claim **7**, where a plurality of vacuum consumers is in communication with the secondary vacuum reservoir and where the device to provide priority to receive vacuum at the brake-booster vacuum reservoir over the secondary vacuum reservoir limits vacuum to the plurality of vacuum consumers.

14. A system for providing vacuum for a vehicle, comprising:

an engine intake system;

a first vacuum reservoir;

a turbocharger with a compressor coupled in the engine intake system;

a second vacuum reservoir pneumatically coupled to the engine intake system;

a first group of vacuum operated actuators in pneumatic communication with the first vacuum reservoir;

a second group of vacuum operated actuators in pneumatic communication with the second vacuum reservoir;

a first vacuum source comprising an engine intake manifold in pneumatic communication with the first vacuum reservoir and the second vacuum reservoir;

a second vacuum source in pneumatic communication with the first vacuum reservoir and the second vacuum reservoir; and

a controller configured to limit air flow from the second vacuum reservoir to the first vacuum reservoir, the first vacuum source, and the second vacuum source when a pressure of the first vacuum reservoir is greater than a first threshold pressure.

15. The system of claim **14**, where the controller is a pneumatically actuated valve.

16. The system of claim **14**, where the controller includes a processor and input and output ports, the system further comprising an electrically operated valve in electrical communication with the controller.

17. The system of claim **16**, where the controller includes instructions to close the electrically operated valve when a pressure of the first vacuum reservoir is greater than a first pressure.

18. The system of claim **14**, where the first group of vacuum operated actuators includes a brake booster.

19. The system of claim **14**, where the second group of vacuum operated actuators includes a compressor bypass valve and a waste gate actuator.

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